CRASH RESISTANT ALUMINUM ALLOY SHEET PRODUCTS AND METHOD OF MAKING SAME

Cross-Reference to Related Application

This application claims priority to Provisional Application Serial No. 60/436,123, filed December 23, 2002.

Field of the Invention

[0001] The present invention relates to aluminum alloys, and more particularly relates to aluminum sheet products in which alloy compositions and processing methods are controlled in order to produce improved crash resistance properties.

Background of the Invention

[00002] The use of aluminum sheet in automotive applications has generally been limited to Aluminum Association 6xxx alloys (Al-Mg-Si) for outer panels and 5xxx alloys (Al-Mg) for inner panels and structural members. In order to maximize the weight savings potential of aluminum, it is desirable to replace relatively low strength 5xxx alloys in the structure with higher strength 6xxx alloys. However, a shortcoming of existing 6xxx auto body sheet (ABS) alloys is their ability to absorb energy during crash situations. This is generally termed crashworthiness.

[00003] Autobody sheet requires a combination of good forming properties along with good strength after paint baking operations. The forming properties require good stretch forming and good bending. This traditionally has been achieved with rapid water quenching from solution heat treat temperatures. However, rapid water quenching often results in distortion, surface irregularities and water staining that are unacceptable for outer auto body applications. Air quenching offers many advantages

over water quenching with respect to eliminating quench distortion problems, but air quenching can lead to poor bending performance.

[00004] The present invention has been developed in view of the foregoing and to address other deficiencies of the prior art.

Summary of the Invention

[00005] The present invention controls alloy compositions and quench rates to produce aluminum alloy sheet products exhibiting good as-processed formability and shape, and good crashworthiness and strength in the artificially aged condition.

[00006] An aspect of the invention is to provide a 6xxx alloy with a desired combination of strength and crashworthiness.

[00007] Another aspect of the present invention is to provide a heat treated and slow quenched aluminum alloy sheet comprising from about 0.5 to about 0.7 wt.% Si, from about 0.5 to about 0.7 wt.% Mg, from about 0.1 to about 0.3 wt.% Mn, and the balance Al and incidental impurities.

[00008] A further aspect of the present invention is to provide a method of treating an aluminum alloy sheet, the method comprising providing a heat treated aluminum alloy sheet comprising Si, Mg, Mn, and the balance aluminum and incidental impurities, and slow quenching the heat treated aluminum sheet at a rate of less than about 200°F/second.

[00009] These and other aspects of the present invention will be more apparent from the following description.

Brief Description of the Drawings

[0010] Fig. 1 is a schematic diagram illustrating an aluminum sheet heat

treating and slow quenching process in accordance with an embodiment of the present invention.

[0011] Fig. 2 is a graph of temperature versus time for a paint bake treatment.

[0012] Fig. 3 is a graph of yield strength versus line speed of a continuous heat treat furnace, illustrating strength properties for two different 6xxx alloys without a slow quench and with a slow quench in accordance with embodiments of the present invention.

[0013] Figs. 4a and 4b are graphs of tensile properties versus paint bake time at 185°C for two different alloys.

[0014] Figs. 5a-5c are computer generated illustrations taken from different views of a sample crash box made of alloy 6060 sheet without a slow quench.

[0015] Figs. 6a-6c are computer generated illustrations taken from different views of a sample crash box made of alloy 6xxA sheet with a slow quench.

[0016] Figs. 7a-7c are computer generated illustrations taken from different views of a sample crash box made of alloy 6060 sheet with a slow quench.

[0017] Figs. 8a-8c are computer generated illustrations taken from different views of a sample crash box made of alloy 6xxA sheet without a slow quench.

Detailed Description of Preferred Embodiments

[0018] The present invention provides aluminum alloy sheet products having favorable crash resistant properties. As used herein, the term "sheet" refers to aluminum alloy products having thicknesses from 0.2 to 6.3 mm. For auto body sheet products, thicknesses of from 0.7 to 3.5 mm are preferred. The aluminum alloy sheet products exhibit favorable crash resistance or crashworthiness properties. For the

purpose of this invention, crashworthiness is defined as the ability of a material to absorb energy by plastic deformation without appreciable cracking. The crashworthiness of the sheet products can be quantified by critical fracture strain (CFS).

[0019] A preferred process path includes the following steps: casting of an aluminum alloy ingot by conventional or continuous methods; hot rolling; intermediate annealing; cold rolling; solution heat treating; and slow quenching, e.g., air quench or minimum distortion water quench. The steps of solution heat treating and slow quenching preferably occur on a continuous heat treater or temper line. After slow quenching, the sheet may optionally be reheated and coil cooled. The optional cooling step may be performed as an off-line batch process. The steps of solution heat treating and slow quenching, in addition to an optional reheating step, are schematically illustrated in Fig. 1.

[0020] In the solution heat treatment step, the aluminum alloy sheet may be run through a continuous heat treater to substantially dissolve soluble phases formed during upstream processing. This process typically involves furnace temperatures of 800 to 1,100°F at speeds from 20 to 150 feet per minute. The temperature and dwell time in the furnace may be adjusted based upon alloy composition and gauge.

[0021] In the slow quenching step, upon exit from the furnace zone of the continuous heat treater, the sheet is quenched at a controlled rate to retain the solute in solid solution. This can be accomplished, for example, with air or minimum distortion water. An aspect of this invention is the use of relatively slow quench rates that minimize sheet distortion while still developing favorable physical properties. As

used herein, the term "slow quench" means quenching at a rate of less than about 200°F/second, preferably less than about 100°F/second. Quench rates for air type processes preferably range from about 20 to about 100°F/second, more preferably from about 40 to about 70°F/second. Water quench rates preferably range from 50 to 1,000°F/sec, more preferably from 100 to 200°F/second.

[0022] In the optional reheating step, a heating unit may follow the quench unit and any coil handling equipment, preferably just ahead of the coiling equipment on the exit end of the line. The heating unit raises the temperature of the sheet such that an elevated coiling temperature can be achieved. A preferred range of coiling temperatures is from about 130 to about 190°F. In the coil cooling step, the warm coil is allowed to cool slowly, typically as a 5,000 to 50,000 lb. mass of metal. This typically results in cooling rates of from about 0.1 to about 5°F/hour.

[0023] In accordance with an embodiment of the present invention, the composition of the aluminum alloy sheet is controlled in order to provide favorable crash resistance properties. The Si and Mg levels are controlled in order to provide high strengths. The Mn level is sufficient to control the grain size of the sheet, particularly during heat treating. Suitable alloys include 6xxx alloys such as 6009, 6060, 6063 and 6005. Typical, preferred and more preferred alloy composition ranges are listed in Table 1.

Table 1

Alloy Compositions (Wt.%)

	Si	Mg	Mn	Fe	Cu	Al
Typical	0.5-0.7	0.5-0.7	0.1-0.3	0.35 max	0.20 max	balance
Preferred	0.56-0.68	0.54-0.66	0.12-0.18	0.15-0.30	0.10 max	balance
More Preferred	0.58-0.66	0.56-0.64	0.12-0.18	0.15-0.25	0.10 max	balance

[0024] A particularly preferred Al-Mg-Si-Mn alloy is listed in Table 2. Table 2 lists the preferred 6xxA alloy compositions and a 6060 alloy composition in wt.percentages, with the balance comprising aluminum and incidental impurities.

Table 2

Aluminum Alloy Sheet Compositions

Alloy		Si %	Fe %	Cu %	Mn %	Mg %
6xxA	target	0.62	0.20	—	0.15	0.60
	min.	0.58	0.15	—	0.12	0.56
	max.	0.66	0.25	0.10	0.18	0.64
6060	target	0.56	0.20	0.075	—	0.55
	min.	0.53	0.15	0.05	—	0.52
	max.	0.58	0.25	0.10	0.10	0.57

[0025] An advantage of the present invention is the improvement in the crashworthiness of the aluminum alloy sheet product, which may be measured by critical fracture strain (CFS) and axial crush tests. Using the typical engineering stress-strain output from a standard r&n tension test, a critical fracture strain can be determined:

$$CFS = -\ln(1 e_{t,eng})$$

in which $e_{t,eng}$ represents the total engineering thinning strain. The total engineering

thinning strain is a function of e_m, σ_m and σ_f:

$$\varepsilon_{t,eng} = f(e_m, \sigma_m, \sigma_f)$$

where e_m is the engineering strain at the maximum load; σ_m is the engineering stress at the maximum load; and σ_f is the engineering stress at the fracture load.

[0026] The following engineering assumptions are made in the development of the CFS: strains in the thickness and width directions are the same before the maximum load (P_{max}); the true stress after P_{max} is a constant; and the width strain is constant after P_{max}. The total thinning strain at fracture may therefore be determined. In accordance with the present invention, a minimum CFS crashworthiness value of about 15 is preferred, with a value of at least 18 being more preferred.

[0027] A typical property comparison for alloys is shown in Table 3.

Table 3

Alloy	**Yield Strength**	**Crush Results**	**CFS**
5083	145 MPa	Good with some cracking on tight folds	18
6060	216 MPa	Good with some cracking at geometric constraints	21
6xxA	244 MPa	Good with some cracking at tight folds	18

[0028] Twelve lots of materials 2.0 mm thick were fabricated. Details of the fabrication are given in Table 4. Prior to hot rolling, each of the cast samples was scalped and preheated at 590°C for 8 hours followed by 560°C for 9 hours. The main variables were alloy composition, use of a slow spray quench at an approximate cooling rate of 150°F/second following hot rolling, and the line speed of the continuous heat treat furnace (CHT). The compositions of the two 6xxA and 6060 alloys studied are shown above in Table 2.

Table 4

STEP	Coil 1 6xxA	Coil 2 6xxA	Coil 3 6060	Coil 4 6060
Hot Rolling	1080 x 10 mm	1080 x 8 mm	1080 x 10 mm	1080 x 8 mm
Hot Rolling exit t. °C	>450°C	>450°C	>450°C	>450°C
Slow Quench after hot rolling	YES	NO	YES	NO
SHT Cont. Furnace	550-570-570 °C spray bar	550-570-570 °C spray bar	550-570-570 °C spray bar	550-570-570 °C spray bar
Speed 1	7 mt/min	5 mt/min	7 mt/min	5 mt/min
Speed 2	11 mt/min	8 mt/min	11 mt/min	8 mt/min
Speed 3	15 mt/min	12 mt/min	15 mt/min	12 mt/min

[0029] The sheet was evaluated in the as received T4 temper and also after a simulative paint bake treatment at 180°C (365°F). Fig. 2 is a temperature-time plot of a thermocoupled sheet sample during the paint bake treatment.

Table 5

Tensile Properties for Sheet Products in T4 Temper

Alloy	Slow Quench	Speed	Test	Rm	ASTM Test Rp0.2	A	Uniform A	r	n
Coil		(m/min)	direction	(MPa)	(MPa)	(%)	(%)		
6060	No	12	L	164	95	29	24	0.43	0.225
			X	155	94	22	21	0.518	0.221
			T	152	88	30	25	0.749	0.215
		8	L	184	108	28	23	0.634	0.23
			X	182	106	23	22	0.634	0.222
			T	178	104	25	19	0.749	0.227
		5	L	192	116	26	21	0.749	0.223
			X	189	115	27	19	0.518	0.216
			T	191	116	26	21	0.685	0.22
6060	Yes	15	L	183	113	28	25	0.595	0.216
			X	187	110	25	21	0.518	0.24
			T	185	108	25	20	0.749	0.232
		11	L	180	111	30	24	0.411	0.219
			X	183	109	27	22	0.277	0.216
			T	183	112	27	22	0.214	0.216
		7	L	187	115	27	21	0.427	0.223
			X	186	113	26	21	0.346	0.223
			T	188	112	26	20	0.267	0.224
6xxA	No	12	L	163	94	28	24	0.629	0.231
			X	167	90	23	21	0.634	0.243
			T	159	91	25	20	0.629	0.222
		8	L	196	109	28	22	0.629	0.246
			X	192	109	25	21	0.518	0.24
			T	189	105	25	21	0.629	0.247
		5	L	209	116	27	22	0.634	0.246
			X	204	119	24	20	0.518	0.238
			T	200	113	25	18	0.629	0.233
6xxA	Yes	15	L	196	118	28	20	0.518	0.228
			X	194	118	28	21	0.343	0.224
			T	188	114	25	21	0.429	0.215
		11	L	210	128	28	22	0.477	0.229
			X	209	129	26	22	0.477	0.225
			T	203	125	23	18	0.524	0.218
		7	L	208	125	26	21	0.682	0.232
			X	209	124	26	21	0.687	0.234
			T	207	124	24	20	0.525	0.233

[0030] The tensile properties of the sheet in the T4 temper are presented in Table 5. There was a slight tendency for the T4 yield strength to decrease with

increasing CHT line speed, which is probably indicative of incomplete dissolution of Mg_2Si at the faster line speed. Minor variations in other T4 properties were found.

[0031] Guided bend tests using T4 sheet pre-strained 10% show that the slow quench is beneficial to bending of both alloys. Both alloys fabricated using the slow quench withstood the maximum sharp bend. Downflange and hemming tests illustrate that both alloys are flat hem capable.

[0032] The sheet r&n tensile properties after the paint bake were measured using 2 inch gage length specimens. Table 6 lists the r&n tensile data.

Table 6

Tensile Properties for Sheet Products after Paint Bake

Alloy	Slow Quench	CHT LineSpeed meters/min	r&n test data (L - direction after PB) YS (MPa)	UTS (MPa)	YS/UTS	Uniform Elong. (%)	Total Elong. (%)	r (avg)	n
6060	No	5 avg	237 239 238	247 249 248	0.96	10.3 10.4 10.4	15.2 16.1 15.7	1.0064 0.9614 0.9839	0.0850 0.0845 0.0848
6060	No	8 avg	230 230 230	238 239 238	0.97	10.1 11.0 10.6	15.5 15.4 15.5	0.9403 0.9982 0.9693	0.0906 0.0910 0.0908
6060	No	12 avg	197 192 194	206 201 204	0.95	9.3 9.7 9.5	15.3 15.0 15.2	0.9267 0.9657 0.9462	0.0958 0.0976 0.0967
6xxA	Yes	7 avg	236 235 236	243 243 243	0.97	10.2 10.9 10.6	17.1 16.2 16.7	0.7234 0.7301 0.7268	0.0897 0.0912 0.0905
6xxA	Yes	11 avg	237 237 237	245 244 244	0.97	10.3 10.7 10.5	17.0 18.0 17.5	0.7626 0.7448 0.7537	0.0919 0.0913 0.0916
6xxA	Yes	15 avg	228 228 228	235 234 234	0.97	10.1 10.5 10.3	15.6 16.4 16.0	0.8057 0.8491 0.8274	0.0917 0.0923 0.0920
6060	Yes	7 avg	237 237 237	245 246 246	0.96	10.0 9.9 10.0	16.4 14.7 15.6	0.7026 0.7120 0.7073	0.0831 0.0830 0.0831
6060	Yes	11 avg	239 236 238	247 245 246	0.97	10.4 10.3 10.4	15.6 16.9 16.3	0.6590 0.6609 0.6600	0.0822 0.0839 0.0831
6060	Yes	15 avg	236 237 237	245 245 245	0.97	10.0 10.1 10.1	15.2 16.5 15.9	0.6953 0.6594 0.6774	0.0804 0.0815 0.0810
6xxA	No	5 avg	249 248 249	257 256 256	0.97	9.8 9.9 9.9	14.8 16.4 15.6	1.0046 0.9965 1.0006	0.0832 0.0831 0.0832
6xxA	No	8 avg	232 231 232	241 239 240	0.97	10.3 10.3 10.3	16.3 16.0 16.2	1.0856 1.0917 1.0887	0.0904 0.0896 0.0900
6xxA	No	12 avg	165 172 169	176 18 2179	0.94	10.1 10.3 10.2	16.4 16.1 16.3	1.0024 0.9479 0.9752	0.1137 0.1060 0.1099

[0033] Fig. 3 plots yield strength of the alloys as a function of the processing variables. The yield strength has the tendency to decrease at the fastest CHT line

speeds due to incomplete dissolution of Mg_2Si. Guinier x-ray data showed the presence of Mg_2Si in the materials processed at the faster line speeds. The influence of line speed on yield strength is most pronounced in the sheet which was processed without using the slow quench.

[0034] Fig. 4a is a graph of Rm, Rp0.2 and A values versus paint bake time at 185°C for the 6060 sample listed in Table 6 which was subjected to the slow quench and a CHT speed of 11 meters/minute. Fig. 4b is a similar graph for the 6xxA sample which was likewise subjected to the slow quench and CHT speed of 11 meters/minute.

[0035] Crash boxes were assembled having a rectangular cross section measuring 63 mm by 133 mm. Welds or rivets may be used at approximately 1 inch on center with the first and last weld approximately ½ inch from the end. The number of spot welds or rivets specified were 20 per flange. An adhesive sold under the designation Betamate 1494 by Gurit Essex is a one-component toughened epoxy that is applied warm along the side seams of the crash boxes, followed by riveting. A pneumatic heated cartridge gun is used to dispense the adhesive at approximately 40 to 50°C (104 to 122°F). The metal components to be joined were also heated to approximately the same temperature to assist in application of the adhesive and improve flow and wettability. The adhesive was applied to warm metal on the flanges just prior to spot welding or riveting. Rivets were installed at the same locations specified for welding. End caps are then welded in place. After assembly, the boxes were paint baked. The paint baked boxes were tested in axial crush. The crush loads and energy absorbed at displacements of 100, 150, and 200 mm is given in Table 7.

Table 7

Axial Crush Test Results of Paint Baked Samples

Sample No.	Alloy	Slow Quench	CHT Line Speed meters/min	Crush (after PB) Max Load (kN)	Mean Load (J/mm)	Energy Absorbed @ (J) 100 mm	150 mm	200 mm
1	6060	No	8 avg	144.7 144.4 144.9 144.7	55.7 56.5 52.8 55.0	5941 6011 5935 5962	8472 8470 8746 8563	11039 11184 10470 10898
2	6xxA	Yes	11 avg	156.3 152.8 157.0 155.4	54.9 58.6 53.4 55.6	6380 6323 6171 6291	8364 8955 8496 8605	10877 11602 10571 11017
	6xxA	Yes	11 avg	162.2 162.2 156.9 160.4	58.4 51.1 57.3 55.6	5932 5505 6690 6042	9146 8000 9149 8765	11563 10119 11361 11014
3	6060	Yes	11 avg	154.6 141.4 140.6 145.5	50.4 53.8 51.9 52.0	6076 6205 5554 5945	7924 8449 8028 8134	9983 10670 10278 10310
	6060	Yes	11 avg	149.1 148.1 153.1 150.1	56.4 55.7 52.3 54.8	5771 6081 6437 6096	8977 8644 8175 8599	11170 11045 10364 10860
4	6xxA	No	8 avg	140.0 147.8 143.8 143.9	51.3 55.6 52.8 53.2	5752 5724 5992 5823	8257 8469 8461 8396	10156 11020 10455 10544

[0036] Computer generated illustrations of the crushed appearance of the boxes are shown in Figs. 5-8. Figs. 5a-c are computer generated illustrations from different view of Sample No. 1 listed in Table 7. Figs. 6a-c are computer generated illustrations of Sample No. 2. Figs. 7a-c are computer generated illustrations of Sample No. 3.

Figs. 8a-c are computer generated illustrations of Sample No. 4. There were no significant differences among the quantifiable crush parameters for the samples tested.

[0037] The performance of the materials met the goals of a sheet alloy product for use in crash critical applications. The paint baked sheet had yield strengths of about 235 MPa, total elongation of 15% and good static crush performance. The T4 properties indicate acceptable formability.

[0038] Whereas particular embodiments of this invention have been described above for purposes of illustration, it will be evident to those skilled in the art that numerous variations of the details of the present invention may be made without departing from the invention as defined in the appended claims.